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Governing Complexity

Design Principles for Improving the Governance of Global Catastrophic Risks

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Abstract

This paper explores the implications of complexity thinking for governing global catastrophic risks (GCRs), in particular a new breed of super-complex GCRs. It offers a novel interrogation of why legacy governance structures are 'not fit for purpose' when it comes to responding to the complex drivers of GCRs. This assessment provides the basis for an exploration of systemic design principles which could serve to guide policymakers and other participants seeking to innovate upon existing governance configurations in the face of mounting global complexity and risk imperatives. This exercise suggests that establishing the right relationship between overlapping complicated and complex domains is a necessary condition for any design criteria underpinning governance of a viable global civilisation.

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I.   Introduction

Articles in the New York Magazine might ask, 'why we don't seem able to imagine climate catastrophe?' (Wallace-Wells 2017). But increasingly the prospect of possible catastrophe and, in the extreme, human extinction, is informing policymaking at the highest levels, as well as society at large (Castelloe 2018). And, many would argue, with good reason. From climate change and ecosystem collapse, to parasitic artificial general intelligence (AGI), the misuse of advanced biotechnologies and nuclear weapons, we confront daunting challenges within an increasingly interconnected globalised civilization, where catastrophic failure anywhere could mean failure everywhere. As Martin Wolf of the *Financial Times* suggests, humanity's efforts to overcome the tragedy of the global commons 'could prove to be the defining story of the century' (Wolf 2012). Martin Rees agrees, suggesting that existential risks make it unlikely that humanity will reach the end of this century without major changes (Rees 2014). Governance scholars predict a rocky road ahead, observing a move from conventional *distributional politics* (who gets what, when and how) to *existential politics* which 'is like distributional politics on steroids: the stakes are whose way of life gets to survive' (Green, Hale and Colgan 2019).

Of course, global catastrophic risks (GCRs) are nothing new to scholars and practitioners working in the well-established areas of climatology, risk management, resilience, and cognate fields.[3] The scholarship is replete with typologies of 'wicked' (and less wicked) problems and classifications of GCRs (Alford and Head 2017; Avin et al 2018). Although rarely addressed explicitly (Harrington 2016; Levin et al 2012), a focus on GCRs in global politics scholarship is also apparent in the sub-domains of environmental and resilience governance (e.g. Galaz 2014). There is also a substantial policy and practitioner literature which provides sophisticated mapping, taxonomies, rolling assessments of global risks (WEF 2019), slow-developing risks (IRGC 2013), and, increasingly, what policymakers might do about them (CSER 2019).

The challenges posed by uncertainty pervade GCR assessments.[4] Other frequently invoked attributes include 'scale, complexity and severity' (CSER 2019, p. 2). This scoping paper drills down on the governance implications of one of those attributes: *complexity*. Why is a deeper appreciation of GCRs as complex phenomena vital to an effective governance response? In addressing the question, this paper highlights the value of complexity theory (or perhaps, more accurately, *thinking*), not simply as a contextual descriptor, but as a conceptual toolkit and mental model to inform effective GCR governance. We explore the plausibility of classifying GCRs along a continuum of

complexity. Some GCRs are highly complex along a series of dimensions, including levels of connectivity, nonlinear dynamics, rapidly changing circumstance, and emergent properties which produce frequent surprises (Young 2017). Chief examples include climate change, ecological collapse and artificial general intelligence (AGI). We contend that such *super-complex* GCRs plausibly present a qualitatively different set of governance challenges to other GCRs, such as weapons of mass destruction or pandemics.

This paper suggests that the sheer complexity of GCRs is overwhelming the organisational logic of the postwar multilateral order. Operating within a Weberian mechanisation-bureaucratisation paradigm, its architects engineered institutions according to certain design principles, including role definition, bureaucratic chains of command, expert specialisation, and legal hierarchies, thus building up capacities to manage and determine *complicated* outcomes. This top-down command and control approach delivered some notable successes, such as the eradication of smallpox by the World Health Organization and control of ozone-depleting substances under the Montreal Protocol. Those core design principles persist today, but are now increasingly rendered obsolete in the face of harder problems playing out in complex technological, economic, ecological and social assemblages.

When it comes to preventing GCRs, inadequate governance models are also coupled to problematic structural constraints, above all the fact that, as Weiss and Wilkinson (2014, p. 213) lament, '[e]verything is globalized – that is, everything except politics'. Buckminster Fuller (1981, p. 218) captured this troubling predicament almost 40 years ago:

> *We have today, in fact, 150 supreme admirals and only one ship – Spaceship Earth. We have the 150 admirals in their 150 staterooms each trying to run their respective stateroom as if it were a separate ship. We have the starboard side admirals' league trying to sink the port side admirals' league. If either is successful in careening the ship to drown the "enemy" side, the whole ship will be lost.*

Unfortunately, we do not currently have global governance structures predominantly built to manage collective action problems, let alone complex GCRs. Designed to also preserve the status quo and reproduce unequal power, existing multilateral structures are increasingly criticised as overly centralised, politicised, bureaucratic and unresponsive to the pressing needs of the global populace (Kennedy 2016). The political lock on "rapid and far-reaching" measures is nowhere more apparent than in preventing catastrophic global warming. As the Co-Chair of the UN Intergovernmental Panel on Climate Change Working Group III acknowledges, "limiting warming to 1.5°C is possible within the laws of chemistry and physics but doing so would require unprecedented changes" (IPCC 2018). Rockström and colleagues (2009) find that three out of nine boundaries for maintaining the sustainable ecosystems required to support human civilisation may already have been breached. Our future governance system will have to contend with intensifying natural and social boundaries for the preservation of human civilisation, from biosphere fragility points, to increasing asymmetric power of individuals to affect disruption,[5] exponential technology, hyper-concentration of wealth – and all within imminently shorter timescales than most people can intuit.

Whether or not existing governance configurations and practice can be repurposed to address super-complex GCRs is an open question. This paper presents a knowledge overview of scholarship and practice directed towards identifying pathways to effective GCR governance. This

body of work contends that policymakers, practitioners and scholars must throw off the shackles of old ways of thinking and embrace a complexity paradigm. Such a shift involves both revisiting the design logics underlying how we build global governance structures, as well as adopting a complex sensibility more capable of responding adequately to instability, surprise and extraordinary change.[6] Understanding GCRs as *complex* – as opposed to *complicated* – problems, characterised by emergent properties, unpredictability, and non-linearity, is vital to this task. We survey an emergent governance scholarship beginning to grapple with the immense complexity of the global system. We also draw on policy scholarship which takes seriously the implications of nonlinear system dynamics for rethinking conventional governance practices and decision-making heuristics. According to complexity leadership theory, while there is a residual role for traditional 'managerial' responses, attempts to address complex drivers of GCRs 'are often ineffective and sometimes even counterproductive' (Homer-Dixon 2007, p. 30). This paper will explore why these scholars believe that we need new ways of thinking about and understanding governance in a complex, interconnected and rapidly changing world.

The paper begins by applying a complex systems perspective to global catastrophic risk. Next, it turns to the challenge of governing GCRs, diagnosing why existing governance design logics and managerial practices are ill-equipped to respond effectively to the complex drivers of these risks. Drawing on complexity theory and governance scholarship, the paper closes by proposing to supplement inherited governance system design and practices with design principles explicitly oriented to dealing with GCRs. In undertaking this exercise, the paper draws on a broad knowledge base to highlight the linkage between drivers and governance design logics, and identify research gaps in our collective knowledge regarding the governance of GCR.

II.   Complexity and Global Catastrophic Risks

GCR governance requires a deep understanding of complex system dynamics and behaviour to be effective. This section identifies GCRs as a complex (as opposed to complicated) problem, with important implications for governance.

1. Complexity Theory: Between Order and Chaos

"I think the next century will be the century of complexity." So said Stephen Hawking in 2000 (qtd in Chui 2000). Judging by the ascendance of complexity theory in popular, corporate and scientific imagination, he is not alone. Complexity theory emerged in the mid-late 20th century across multiple disciplines, most prominently in physics, biology and mathematics (see: Lorenz 1963; Prigogine 1968; Mandelbrot 1982). Today, complexity theory spans a vast range of disciplines including the social sciences, propelled by a desire to understand system behaviour, from the macroeconomy to forest ecosystems, the human brain to formal organisations. Scholars argue that complexity is intrinsically transdisciplinary, exposing the fallacy of any clean division between 'social' and 'natural' domains (Urry 2003).[7] Yet, despite its broad applicability and potential for analytically coping with the still poorly understood complexity of large-scale systems, many scholars remain reluctant to embrace a truly systemic perspective. Byrne and Callaghan (2014, p. 261) are right that we still 'need a demystification of complexity thinking'.

One reason for this reluctance relates to its disputed status as a theory. Indeed, complexity theory does not have a single, clearly defined focus and it does not aim to produce any universally predictive generalisations (Morçöl 2012). As such, many scholars concur that complexity is 'less a definitive theoretical corpus than a conceptual toolkit' (Bousquet and Curtis 2011, p. 45), with albeit powerful applications across fields as diverse as computing, medicine and military strategy. A minority view, well-expressed by Robert Cox (2001, p. 46), might counter that theory in a complex world should not be seeking to uncover the 'ultimate reality of the universe', but rather, offer 'a transitory snapshot of a world in perpetual motion…it has to show the interactive properties of a system – albeit an open system in which the homeostatic mechanisms that maintain closure can be disrupted by forces that open the way for a change'. For our purposes, it is enough that complexity provides *a way of thinking* that challenges traditional scientific methods. Its central proposition is that much of the world and most of the social world consists of complex systems that are dynamic and constantly evolving. (Byrne and Callaghan 2014, p. 8). All systems are composed of multiple elements that interact with each other and their environment in non-linear ways, giving rise to emergent properties – and major headaches for efforts at predictive modelling.

Complexity demands that we think differently. It challenges one of the fundamental tenets of Western thought, the Cartesian notion of infallible certainty (Prigogine and Stengers 1996). It also upends the idea derived from Newtonian physics that 'you could understand the world, all of nature, by examining smaller and smaller pieces of it. When assembled, the small pieces would explain the whole' (John Holland qtd. in Blakeslee 1995). In closed or *complicated* systems such as a jet engine, reductionism works well. But it falls down when applied to open or *complex* systems where the whole of the system emerges from the interaction of its components. As a result of such

emergence, the whole system has properties that are distinct from the aggregation of its underlying components. In other words, if we are dealing with a complex system the whole is different from, not just greater than, the sum of the parts (Anderson 1972). This observation has radical implications. Whereas mechanical problems within a complicated system are predictable with a reasonable degree of certainty, the same cannot be said for complex systems which are 'more spontaneous, more disorderly, more alive than that' (Waldrop 1993, p. 12). Some political scholars have taken these insights to heart, advocating evolutionary biology as the more productive analogy for the social sciences (Bernstein et al 2000).[8] However, they confront stiff opposition within a discipline which continues to privilege causal identification, experimental and large-N studies as the touchstone of 'good' social science (Monteiro 2012).

2. Key Features of Complex Systems

Complexity lacks a single definition. Although we have an intuitive notion of what it means, it is notoriously difficult to describe or explain. 'We know a complex system (or think we do) when we see it' (Mobus and Kalton 2015, p. 169). Despite the difficulty of pinning down an exact definition, scholars have identified a number of key features that are shared by complex systems across different fields and disciplines:

Complex systems are open as opposed to closed. Complex systems comprise multiple elements that interact with each other and their environment. They are open in the sense that they are not self-contained, their boundaries are fuzzy, and they can be profoundly influenced by external events. Notably, social systems are particularly open and appear to be more complex than natural systems because they 'are composed of the actions and relations of human beings, each of whom is a complex biological and psychological system' as well as 'an interpretative and purposeful actor' (Morçöl 2015, p. 83). Consider how a financial crisis jumps across political, economic and technological system boundaries, impacting everything from election outcomes to food prices to infectious disease outbreaks (Hossain et al 2010). Structurally, globalisation has produced unparalleled open systems, with highly coupled and interdependent technology, materials and economic systems forming a tightly-coupled substrate upon which an increasingly complex (and fragile) globalised civilisation now depends (Centeno et al 2015).

Complex systems exhibit emergent properties. Their behaviour arises out of the constant interaction of system elements with each other and their environment. Importantly, a complex system cannot be understood solely as an aggregation of the properties of its parts, but only in terms of the *relationships* between them. As such, a complex system is generated from the bottom-up. This process is called emergence and is considered to be 'the defining characteristic' of complexity (Holt, Collopy and DeTurris 2016, p. 29). Our human-built governance systems are interfacing with systems of ecology, human cognition, social dynamics and economic behaviours, all of which produce emergent processes which often confound efforts to prevent or manage risk (Centeno et al 2015). The subprime crisis which engulfed the world economy in 2008 is in many ways a story of emergence (Oatley 2019).

Complex systems produce nonlinear outcomes. Because we have a 'natural propensity to think linearly', we often expect changes to be additive and proportional to input (West 2017, p. 47). Many of our dominant policy frameworks reflect this belief in clear and unidirectional causal relationships,

such as the expectation that more aid will proportionally translate into more development (Geyer and Pickering 2011). However, in complex systems, relationships do not follow linear and controllable patterns and they cannot be easily expressed mathematically or plotted neatly on a graph. As physicist Nigel Goldenfeld puts it, "[c]omplexity starts when causality breaks down" (qtd. in Editorial 2009, p. 1). Disruptive events can be magnified or dampened by endogenous feedback loops. Positive feedback loops reinforce change tendencies and can sometimes lead to large unforeseen consequences – the proverbial 'butterfly effect' (Lorenz 1963). A well-known example is the ice-albedo feedback loop (He et al 2019). In contrast, negative feedback reinforces system stability.

Complex systems are able to self-organise. Organisation within a complex system occurs in the absence of central control or external manipulation. Such self-organisation is a product of the simultaneous actions of individual elements (or agents) and it usually involves parallel processes of adaptation and co-evolution. Co-evolution within social systems refers to the system-level outcome of individual adaptation strategies: 'as we evolve, so do our competitors; to remain fit, we must adapt to their adaptations' (Kauffman 1995, p. 27). Because of this ability to adjust collectively to change and new realities, complex systems are also sometimes referred to as complex adaptive systems (Holland 1992). Complex systems are often capable of demonstrating remarkable resilience, even in the face of large disruptive events (Middleton and Latty 2016). Indeed, perhaps counter-intuitively, for something to be, on average, resilient to collapse, it *has to be* complex (Page 2011). Complicated human-built infrastructures, such as electricity grids or computer networks, are inherently fragile to collapse, as they cannot self-repair (Laprie, Kanoun and Kaâniche 2007). The breakdown of large-scale complicated systems, such as critical food supply chains, can have very complex consequences (FPDI 2019). That said, complex systems can also become fragile if adaptation strategies fail or tipping points are reached, unleashing auto-destabilising, positive feedback loops.

Table 1 provides a summary of the key differences between complex systems and complicated or closed systems. One final point: while unpredictability is an 'inherent and inescapable property' of complex systems (Boulding 1987 p. 116), this does not mean that complex systems are a product of pure chance. Elements do not randomly interact with each other, but usually follow certain rules. These rules can be simple, such as those which allow birds to flock in intricate coordinated patterns, or they can be vertiginously complicated and subject to constant change, as in the case of most social norms. While we cannot predict systemic behaviour on the basis of these rules, we can identify behavioural patterns and broad directions of change. This makes complex systems at once rule-bound, surprising and, perhaps, governable.

Table 1. Complicated or Complex? Key Differences

Complicated Systems	Complex Systems
Complicated systems are closed, their boundaries relatively fixed, impermeable and easy to determine.	Complex systems are open, making it difficult or impossible to determine their boundaries.
Complicated systems are ordered and deterministic. They can be fully understood in terms of the properties of their component parts and they always tend towards equilibrium.	Overall behaviour of complex systems is not determined by the properties of their elements but their interactions. The system is usually far from equilibrium but without dissolving into random disorder, it exists 'at the edge of order and chaos' (Waldrop 1993).
Cause and effect relationships are linear such that for each input to the system there is a proportionate output. We can identify a clear cause for each observed effect and predict system-level outcomes of each change.	The relationship between cause and effect is non-linear and effects are usually the result of several interacting causes. Due to feedback loops, we cannot establish clear cause-and-effect relationships or predict system-level outcomes.
Complicated systems can only evolve with the help of an external force. System elements are static and not able to adapt to changing conditions on their own. If a key part of the system breaks down, the whole system will stop functioning, unable to repair itself.	Elements in a complex system are able to learn and adapt to changing conditions. Simultaneously adapting elements give rise to self-organisation. As a result, complex systems can display remarkable resilience and sometimes even continue functioning if key system elements break down.
Because cause and effect relationships in complicated systems are stable over time, any kind of change is reversible.	In complex systems, change creates path dependencies that may be difficult to alter. If we could turn back time to the same starting conditions, the system is unlikely to evolve in exactly the same way.

3. A Complex System Perspective on Global Catastrophic Risks

We understand global catastrophic risk to refer to the threat that individual failures, disruptions or accidents pose to a global system through processes of contagion. Due to the tightly coupled linkages of global social, technological and ecological systems, societies confront multiple

emergent and systemic global risks that threaten 'the possibility of a catastrophic regime shift or even breakdown of a global system that involves many interacting elements that are poorly understood' (Lucas et al 2018, p. 294).

Some of these risks are not new and largely external to human systems, such as the risk of a large asteroid impact or a volcanic super-eruption. Others are not new but have taken on a new dimension in today's interconnected world, such as the risk of deadly pandemics. Further risks are relatively new and entirely human-made, but largely dependent on decisions made by a few key individuals, such as the risk of nuclear war or out-of-control scientific experiments. Finally, we identify a new category of super-complex global catastrophic risks that are inherently global and endogenously arise out of the complex interactions between human and non-human (socio-technological, natural technological and technological-natural) multi-dimensional systems (Avin et al 2018).

3.1.   From Complex to Super-Complex Global Catastrophic Risk

Environmental breakdown due to climate change or mass biodiversity loss poses perhaps the greatest known global catastrophic risk, constituting 'a new, highly complex and destabilised 'domain of risk' – which includes the risk of the collapse of key social and economic systems, at local and potentially even global levels' (Laybourn-Langton, Rankin and Baxter 2019, p. 5). A new category of highly or 'super' complex GCRs is arguably emerging. These risks are different, not due to their scale or severity, but rather the governance challenge they pose due to unusually high levels of complexity and the systemic nature of the problem. A move from complex to super-complex is observable along three key dimensions:

- *Number and diversity of interacting elements.* Larger numbers of diverse elements produce possibilities for more – and different types of – interactions. Human systems have grown dramatically and become more diverse, enabling far more interactions among individuals. Given that super-complex GCRs, such as climate change, arise directly out of myriad micro-interactions, virtually all individuals, often unaware, are implicated in their intensification. Therefore, by extension, only unprecedented levels of collective action will be enough to mitigate this category of risk (Levin et al 2012).

- *Openness of large-scale and nested systems.* Modern global systems are unbounded, meaning that their boundaries are difficult to determine and changes in one system may jump boundaries and lead to unexpected changes in other systems. Crucially, human social, economic and political systems are also 'nested' within, and dependent upon, natural systems that we neither fully understand nor control. Governing super-complex GCRs must contend with this novel 'co-evolutionary experiment on a planetary scale' as humanity and nature proceed to transform each other (Holling 1994).

- *Speed of connectivity within systems.* The 'density, intensity and pace' of increased interactions compounds the challenge posed by super-complex GCRs (Homer-Dixon 2001, p. 119). New technologies have produced 'tightly-coupled' complicated systems where the speed of connectivity among hubs makes it difficult or impossible to buffer against isolated failures, which may then devolve into cascades of socio-technological disasters throughout the entire system (Perrow 1984). Further undermining system stability, incentives to

optimise for one value (e.g. efficiency or profit) may undermine system redundancy – the ability of the system to recover from the loss of critical hubs in the network.

Super-complex GCRs are particularly difficult to understand and even more difficult to govern. As the next section highlights, their causes are diffuse, and their effects are open-ended and unpredictable. In turn, as will be explored, mitigating super-complex GCRs will require a profound change in human behaviour and cognition. This is a tremendous challenge. As Yudkowsky (2008, p. 114) observes, 'people do not become any smarter, *just* because the survival of humankind is at stake'. Given an exponential increase in the ability of humans, individually and as a collective, to affect change at a planetary scale, this is a particularly sobering observation.

3.2.   Mechanisms Exacerbating Global Catastrophic Risks

How does risk fragility arise in global systems? How might global systems tip from weakened resilience to catastrophe? Complexity theory is well-suited to addressing such questions. In particular, it helps us to identify some of the underlying mechanisms which propel accumulated stresses, weakened resilience, and multiple shocks towards situations of system breakdown or collapse. Conventional risks, such as air crashes, floods, and heart attacks, can be relatively easily isolated and assigned reasonable probabilities. In contrast, complex – and in particular super-complex- GCRs threaten to cause breakdown at a systems level, as opposed to the breakdown of individual parts components. That is, 'systemic risk is the risk of a chain reaction of falling interconnected dominos' (Kaufman 1995, p. 47). This dimension of 'a large potential threat within a complex web of interacting elements is a key difference between systemic and conventional risks' (Lucas et al 2018, p. 294).

System stresses which make GCRs more difficult to govern are exacerbated by the three multipliers identified in the previous section: (1) number and diversity of elements, (2) openness and nestedness of systems, and (3) speed of connectivity. Due to these systemic multipliers, super-complex GCRs are extremely difficult to contain due to contagion effects and amplification mechanisms. The unpredictability and velocity of change within complex systems poses a hard test for human cognitive capabilities. It is often hard to identify a single, distinct cause and risks may be perceived and evaluated very differently by stakeholders (IRGC 2018). Indeed, Homer-Dixon (2011, p. 7) argues that in a complex world, it is more appropriate to speak of 'uncertainties' than 'risks' given that we 'don't have the data to estimate the relative probabilities that the system will evolve along one pathway or another'.

It is no surprise then that governing actors struggle to understand and respond to extreme risks, especially those that appear remote or develop slowly. Indeed, time urgency (and prevarication) is a key concern in this domain. Some observers believe that 'the duration of any future breakdown or collapse is likely to be dramatically compressed'; the proverbial cliff edge (Homer-Dixon 2007, p, 125). Others contend that when it comes to climate change, white-water rapids serve as the more appropriate metaphor. We are 'unlikely to have a single catastrophic point of failure, [rather it] might, to stretch the analogy, be a series of increasingly severe drops' (Watson 2016). Whether cliff edge or rapids, or both, the risk of breakdown is heightened by mechanisms endogenous to complex systems, including:

Tipping points and thresholds: Sudden, irreversible and system-wide change can occur if interacting feedback loops drive the system towards a 'tipping point' – a critical threshold after which 'a minor trigger can invoke a self-propagating shift to a contrasting state' (Scheffer et al 2012, p. 344). In ecosystems, a tipping point may be reached when a keystone species – species that provide vital services to a wide range of other species – can no longer reproduce. In tightly-coupled systems exhibiting scale-free networks,[9] 'non-redundant critical hubs' such as megacities, key food distribution hubs, or nuclear power plants, pose particular hazards in high-velocity networks and are a key concern for health, infrastructure and military security experts (Homer-Dixon 2007, p. 118).

Fast feedback effects: High speed connectivity within tightly-coupled systems raise the risk of fast positive feedback effects within a system with little buffering capacity to respond to surprising developments. This mechanism is illustrated by Bostrom's famous thought experiment 'the paperclip maximiser', which he uses to illustrate the existential dangers posed by AI absent machine ethics (Bostrom 2003). Underlying the paperclip maximiser scenario is the possibility of powerful AI systems developing faster feedback loops more adaptive than biology, and not commensurate with biology.

Cascading failures: Systemic risks can result from exogenous shocks and/or endogenous stresses that arise out of interactions between elements in a complex system. In highly interconnected systems, even small shocks or point failures could result in system-wide cascading failures. Because global complex systems are open and interlinked, inter-systemic cascading effects are also likely to occur, so that the effects of systemic risks 'may be felt across systems seemingly well-buffered from each other' (Lucas, Renn and Jaeger 2018, p. 1). A major cyber-attack, for example, could quickly cascade through critical common global infrastructure – especially, energy, food and information systems and supply-chain choke points (WEF 2019, p. 69).

3.3.   Global Catastrophic Risks Are Complex Problems

Why is an understanding of complex system dynamics so important to governing GCRs? Reflecting the pervasive view that legacy multilateral structures are no longer 'fit for purpose', complexity thinking brings into focus the reasons underlying the governance gap between actor intentionality and expectations versus actual policy outcomes. Awareness of the properties of complex systems, above all emergent causality and nonlinearity, encourages scholars and practitioners to reframe the problem and, in doing so, seek out new understandings of what complex governance entails. In this spirit, GCR governance first requires identifying GCRs as a complex problem. As policy scholarship has demonstrated, accurate problem identification is crucial to devising an appropriate governance response (Peters 2005). Correct specification of the problem brings into sharp relief the need for governance strategies capable of accommodating 'local, nonlinear, nonalgorithmic, dynamic interactions' (Cilliers 2000, p 46). Ultimately, as will be developed, GCR governance is less about the retroductive 'hunting for causes' than the 'informing of action directed towards the achievement of futures' (Byrne and Callaghan 2014, p. 190).

A complex problem can be distinguished from a *complicated* problem. Complicated problems follow an ordered and linear logic. They can have many components, but the relationships between the components are fixed and clearly defined. We can use a reductionist, analytical approach to understand, control and predict the behaviour of complicated systems, such as a jet engine. A

complicated system is the sum of its parts. As such, complicated problems can be highly intricate, but they are ultimately 'knowable through proper investigation, and relationships between cause and effect, once discovered, repeat' (Snowden 2005, p. 46). A rules-based governing framework is appropriate to establish order and control. There are 'right answers', but not necessarily a single one. As such, decision-makers must rely on data-gathering and expert input to analyse individual parts of the problem and put them back together (Snowden and Boone 2007).

Complex problems are fundamentally different to complicated problems. Due to emergent properties, the Newtonian mechanics of cause and effect are no longer applicable, meaning that problems cannot be understood and solved by breaking them down into component parts. Complexity is a realm of 'unknown unknowns', making prediction impossible and the search for a 'right answer' elusive. This does not mean, however, that complex problems are completely random. Emergent patterns can be discerned, and heuristics can provide guiding principles, albeit ambiguous ones, to understand and respond to the problem (Snowden 2005). Heuristics – informal methods, trial and error, rule of thumb, intuitive judgment – are important and ubiquitous tools for making decisions under conditions of uncertainty (Tversky and Kahneman 1974). For our purposes, as will be developed, heuristics highlight the importance of human judgement in tackling complex problems where no simple direction of causality is apparent, similar processes play out differently across time and context, and behavioural patterns within the system are contingent and relationship-based rather than fixed and rule-based (Cilliers 2000).

Super-complex GCRs such as climate change, ecological collapse and misaligned AI that arise out of the interactions of billions of different elements are perhaps the epitome of a complex problem: they involve significant uncertainties, demand multiple perspectives capable of accommodating social and natural system dynamics, and there are certainly no straightforward answers. It is important to flag that policy problems will often simultaneously contain complicated and complex elements. It is therefore not always straightforward to determine whether a problem is (primarily) complicated or complex. Recalling the quote attributed to Einstein at the opening, such determinations matter. Because we are less familiar with governance tools that can help us address complex problems, these problems are often misclassified and treated as complicated, resulting in ineffective, even counter-productive, attempts to 'engineer' expert-driven linear solutions. The remainder of this paper explores the implications of this observation for GCR governance, highlighting the strengths and weaknesses of existing governance orthodoxies before framing possible complex governance design alternatives as objectives for the future.

III. Governing Complex Catastrophic Risk: Why Existing Structures Are Not Fit for Purpose

Internationally we have…some architectural drawings for modest renovations in international structures that are several decades old and not up to present building codes. Blueprints sit in filing cabinets while unstable ground and foundations shift under feeble existing structures….'

Weiss and Wilkinson 2014 (p. 214)

Really-existing global governance structures, understood principally as the domain of legalised interstate multilateralism, are widely viewed as unfit for purpose, incapable of responding to pressing global problems (Goldin 2013). The UN Secretary General, Antonio Guterres, warns of "a great fracture" imperilling the entire multilateral system (qtd. in UN News 2019). Of course, global governance does not begin and end with nation states and multilateral organisations. A host of other actors, processes and mechanisms are now involved, from private market actors to civil society groups. But where powerful global forces are influential in producing local change, many question their legitimate functioning (Hameiri and Jones 2016). Others highlight how unchecked private governance regimes are enabling vast inequity on a global scale (Mattli 2018). While few disagree that legacy structures require reform if they are to respond to the threat of global catastrophic risks (GCRs), the scale of reform required provokes vigorous debate (see Plesch and Weiss 2015 vs Patrick 2014). An avalanche of expert advice on what must be done belies the relative lack of consensus over causal explanations for global regulatory failure, or its solution. The debate also highlights deeper faultlines, with 'pragmatists' confining their problem-solving within the constraints posed by 'sovereign interests of great powers' and the 'structural integrity of the [multilateral] system' (Hale, Held and Young 2013, p. 528), while 'transformationalists' urge scholars to 'imagine a fundamentally fairer and more sustainable international system for the future' (Weiss 2013, p. 24).

What can complexity thinking bring to this debate? First, complexity brings to the fore foundational questions underpinning a 'policy-relevant science of institutional design' (Wendt 2001, p. 1047): How and why have design choices been made in the past? What works? And what goals should we pursue? Second, it invites governance scholars – pragmatists and transformationalists alike – to imagine something other than the present, because the 'intelligence of complexity' compels us to 'explore the field of possibilities, without restricting it with what is formally probable' (Morin 2007, p. 29). This section identifies the true design problem which GCRs pose to global governance structures, why the legacy toolkit – the assumptions, heuristics, models, and practices conventionally employed to solve problems – is unlikely to suffice, and why engaging complexity within governance research and policy is now vital.

1. What is the Problem?

What is the design problem confronting global governance structures? There is no shortage of candidates. Background system conditions provide important clues. As Homer-Dixon (2007, p. 14)

argues, globalisation is 'not just a process of growing economic interdependence' but rather 'an almost vertical rise in the scope, connectedness, and speed of *all* humankind's activities and impacts'. Decision-makers must contend with an extremely open, rapidly-changing global system, intimately linked with large-scale natural and technological systems. From climate change to health pandemics to financial crises, it is now impossible to ignore 'the power of the global' and 'the centrality of global dynamics of logics' within local political processes and outcomes (Hurrell 2015, p. 14). And yet, while such global problems demand global solutions, that demand has not translated into structures capable of governing at this highest level of political assembly. International regimes, and in particular their core multilateral structures, remain significantly constrained by the competing preferences of their territorially-bound political masters: nation states (Hawkins 2006).

Post-war legacy structures are widely viewed as having served to facilitate interstate cooperation, deepening interdependence and globalisation as a result (Abbott and Snidal 1998; Krasner 1983). This has set in motion processes of 'self-reinforcing interdependence', helping 'create conditions that, ironically, now impede [multilateral] effectiveness' (Hale, Held and Young 2013, p. 66). Hale and Held argue that self-reinforcing interdependence is producing four 'second order' cooperation problems: growing multipolarity, harder problems, institutional inertia, and fragmentation (Hale and Held 2018, p 130). Zürn (2018) takes a more overtly political angle, arguing that the arbitrary authority accrued to these supranational structures is endogenously fomenting conflict, contestation, and resistance from below, fuelling legitimation problems and demands for change. Other scholars question the strong cooperation narrative in liberal accounts of multilateralism, reminding colleagues of the persistent need to be critical about how governance problems have been defined and governance arrangements arrived at. It is salutary to remember that multilateral structures have not been predominantly designed to attend solely to 'well-understood collective action problems', but have always been in the business of 'managing power, especially unequal power' (Hurrell 2015, pp. 1 and 2).

The governance of GCRs must contend with these multiple power-political and organisational challenges. It is a formidable task, made harder by the fact that the architects of the post-war multilateral order did not have the technical and conceptual apparatus to design solutions for the types of global problems which these institutions are now called upon to solve. Hale, Held and Young (2013, p. 81) argue that 'problems have got harder' both in their 'extensity' ('scope of problems has increased') and their 'intensity' ('problems penetrate more deeply into societies'). Hale, Held and Young make an important point. Legacy structures, from the UN Security Council to the General Agreement on Tariffs and Trade (subsequently the World Trade Organisation), were originally geared towards managing complicated problems such as maintaining peace and security and tariff harmonisation among industrialised nations. Environmental agreements now require discussing a host of complex social, environmental and cultural issues – carbon emission mitigation, financial assistance to facilitate climate adaptation, compensation for loss and damage – about which countries sharply disagree. Multilateral venues must now wrestle with this 'four dimensional spaghetti' of competing demands provoked by climate negotiations (CarbonBrief 2018).

A class of complicated problems of an earlier period reflected unusual conditions, which have since undergone a marked deterioration (Coen and Pegram 2018). However, importantly, harder problems are longstanding. Smallpox eradication, achieved in 1979 under the auspices of the World

Health Organization, could be mistaken for a complicated problem that was relatively easy to solve once cause-effect relationships were established. However, closer investigation reveals that 'success hung in the balance on many occasions', punctuated by 'unexpected events', 'unexpected successes', and the 'emergence of needed leadership' (Henderson and Klepac 2013, p. 6). Indeed, it remains the only human-transmitted infectious disease to be eradicated by deliberate means (Henderson 2012). Scrutiny also qualifies prominent claims of WHO top-down success, with experts on the ground confronting 'a sclerotic WHO administration [which] often thwarted or actively impeded what appeared to be logical initiatives' (Henderson and Klepac 2013, p. 6). Another instructive example is the Montreal Protocol on Substances that Deplete the Ozone Layer, ratified in 1987 and widely regarded as the most successful environmental treaty. Ozone depletion has often been portrayed as displaying the hallmarks of a complicated problem; a relatively bounded, quantifiable and well-understood problem that required collaboration of a limited number of key stakeholders (Hulme 2009). However, even here, complexity arises in unexpected failures – such as the illegal production of ozone-depleting substances in East Asia (EIA 2018) and unintended consequences – such as the increase in use of other ozone-depleting chemicals (Vandenbergh, Vreeland and Atwood 2019).

While descriptively instructive, 'extensity' and 'intensity' provide only partial insight into the true design problem posed by global policy dilemmas. Specifically, the terms fail to engage fully with the implications of key characteristics of complex systems introduced in Section I: self-organisation; emergence; system openness; and nonlinear responses to changes. Complex problems have always been hard, and ubiquitous. However, 'information-age threats' have added a new quality, making global problems even more 'diffuse, dispersed, multi-dimensional, non-linear and ambiguous' (Arquilla and Ronfeldt 2001, p. 2). We do observe a move towards *more* complexity, exemplified by the advent of super-complex GCRs which have 'the potential to inflict serious damage to human well-being on a global scale' (Bostrom and Ćirković 2008, p. 1). The imperative of avoiding, surviving, and limiting the damage of inevitable disaster provides welcome clarity to the question: what goals should we pursue? Legacy actors, structures and toolkits are, however, ill-equipped to respond to the corollary question: what works? Their rootedness in an earlier imaginary of politics as 'orderly', 'stable' and 'state-driven' leaves them disorientated within the new 'complexity sensibility', as Rosenau (1999, p. 50) foresaw 20 years ago:

> *Where earlier epochs were conceived in terms of central tendencies and orderly patterns, the present epoch appears to derive its order from contrary trends and episodic patterns. Where the lives of individuals and societies were once seen as moving along linear and steady trajectories, now their movement seems nonlinear and erratic, with equilibria being momentary and continuously punctuated by sudden accelerations or directional shifts.*

The design problem, simply put then, is complexity. However, the problem also lies in how decision-makers are wired to respond to these types of problems. The implications for governance of a rapid shift into more or super-complexity are sobering. It should be clear that even the most powerful states are struggling to comprehend the governance implications of super-complex GCRs, and could easily make the situation worse (Spratt and Dunlop 2019). Perhaps less obvious, the same observation is likely to be true of existing multilateral structures, even if they were supremely resourced and empowered. Such reflections demand that governance scholars critically rethink whether 'present building codes', 'blueprints' and 'modest renovations' are adequate to the task.

As Wendt (2001, p. 1042) argues, the 'premise of real-world design is that the future is open, that we have genuine choices to make, that voluntarism rather than determinism rules the day'. Departing from that premise, the next section examines why the legacy toolkit – the assumptions, heuristics, models, and practices conventionally employed to solve problems – must be supplemented by a new governance perspective informed by complexity thinking.

2. It's Complicated: The Limits of the Legacy Toolkit

How is it that our institutional efforts to regulate interstate conduct have produced the very conditions whereby our mechanisms for dealing with a more volatile world are now more fragile and susceptible to failure? While some scholars might disagree with this view (Drezner 2014), few well-informed observers share their confidence (Elliott 2019). For complexity theorists, this observation comes as no surprise. Complexity increases 'as functions and modifications are added to a system to break through limitations, to handle exceptional circumstances, or to adapt to an environment itself more complex' (Arthur 1994, p. 70). As discussed in Section I, more complexity is not necessarily a bad thing. Complicated human-made systems, however, are often maladaptive; new technologies, procedures, and structures are still ever-more complicated and, as a result, less resilient. In turn, vested political and economic interests will often advocate new layers of complicated bureaucracy to 'block or divert policies that genuinely address the problems' underlying causes' (Homer-Dixon 2007, p. 267).

The problem also lies at a more axiomatic level. As Geyer (2003) notes, the present multilateral system was established when the linear reductionist paradigm reached its zenith in the social sciences, as well as in the Western policy community. Operating within a Newtonian-Cartesian paradigm, strongly informed by an ascendant neoclassical economics, the architects of the multilateral system engineered its structures according to certain design principles, including role definition, bureaucratic chains of command, expert specialisation, legal hierarchies, and the building up of capacities to tackle very specific problems. Although reform and the addition of new components is a feature of past decades, updates generally reinforce old design logics with increasingly dysfunctional results as the formidable difficulty of managing exceedingly complex social, technological and natural systems becomes more apparent (Homer-Dixon 2007, p. 266). The failure of the complicated paradigm for resolving complex problems is particularly evident in the environmental domain, with the Paris Agreement hailed as a paradigm shift from a 'regulative' to a 'catalytic' logic of governance (Hale 2017). However, the Agreement still implies an astonishingly challenging (and intrusive) super-structure of financing, monitoring, scientific and enforcement mechanisms.

Decision-makers must now contend with a governance reality which requires navigating a continual cycle between the politics and multi-scalar boundaries of complicated and complex problems. The legacy toolkit remains important to determining 'what works' in relation to complicated social interventions in appropriate contexts: highly constrained environments, conducive to order and prediction, and amenable to *determining* complicated outcomes (such as a hospital operating theatre). But political outcomes are almost always multi-causal. As Bernstein et al. (2000, p. 52) observe, IR scholars have often not specified 'carefully the temporal and geographic domains to which their theories are applicable. We suspect that those domains are often narrower and more constrained than is generally accepted'. Tackling problems embedded in complex social systems

where linear causality breaks down raises the key question: how to reconstitute a new toolkit which can *enable* desirable complex outcomes? The latter implies shaking up established understandings of governance.

Complex problems defy command and control. The ideal image of a top-down sequence of authoritative control has long been problematised (Simon 1974). Yet the image persists in New Public Management scholarship, at least in principle (Edelenbos and Eshuis 2009). The self-organising properties of a complex system challenge the prevalent assumption that an agent is or can be held responsible for controlling events. In part, this is because a controlling agent cannot be separated from the system. In other words, they are embedded within the system, divesting them of a controlling 'view from nowhere' (Cilliers 1998). Organisational systems with tight coupling and high interactional complexity have long been viewed as beyond the full control of their operators (Perrow 1984). Uncertainty regarding the strategies of other agents means that those who define themselves or are defined by others as decision-makers will not only 'have to form [their own] subjective beliefs', but also 'subjective beliefs about [the] subjective beliefs [of other agents]' (Arthur 2015, p. 5). As such, political will may be directed towards controlling the complete system, but effective system control does not follow (Teisman, Gerrits and van Buuren 2009). That high interactional complexity increases the risk of failure due to the difficulty of effectively monitoring interaction, is well documented in a large scholarship on post-delegation behaviour in multi-level governance systems (Coen and Thatcher 2008).

Complex problems require flexible goal-setting. What goals should we pursue? The question remains important. However, goal-setting can reinforce assumptions of a relatively linear and predictable environment, blinding planners to contextual and complex processes. Experts who make successful decisions under uncertainty, high stakes, time pressure, and organisational constraints have been shown to begin with vaguely defined goals (Kahneman and Klein 2009). The definition of broad and flexible goals or principles can help steer collective behaviour towards more sustainable outcomes (Young 2017). Complexity theory, described as a "science for central uncertainty", posits that while you can comprehend the present and map pathways from the present, you cannot define a predetermined outcome (Snowden qtd in Rutt 2019). From this perspective, 'governance thereby works 'backwards' – from the problem – not forwards to achieve some collective policy-goal (Chandler 2014, p. 62). Governance becomes less about 'goal-based instrumental policy-making', than comprehending 'the processes and capacities that already exist and how these can be integrated into policy understandings' (ibid, p. 58). Public management experts have advocated abandoning top-down, target-driven management processes to instead 'focus on the design of processes – especially ones that enable relationships' (Muir and Cooke 2012, p. 9). In the words of a leading complexity theorist, "we should manage the evolutionary potential of the present, rather than aiming towards some idealized future state" (David J. Snowden qtd. in First Human 2018). In a rare application to IR, Geyer and Pickering (2011, p. 14) expand upon this idea of managing 'a general direction':

> *The realm of creative complexity is generally the most productive for human systems. It combines a stable evolving framework that establishes core boundaries with as wide a variety of local interactions as possible. Systems in this realm have a general direction, but are not rigidly locked into a particular pathway.*

'Complexity is a problem word and not a solution word' (Morin 1994, p. 10). Engineering 'expert' solutions will not suffice when it comes to complex problems (Boone and Snowden 2007). In complicated contexts, where conditions and relationships are orderly, knowable and linear, 'techno-rational elites and decision-making are [seen as] the ideal actors for obtaining the best possible outcomes' (Geyer and Pickering 2011, p. 6). However, a complex system always retains the capacity to surprise even well-informed observers (Mitchell 2009, p. 54). Crucially, complex problems are not isolated events to be solved in isolation. Instead, they are relationally constituted: problems are the effect of large numbers of nonlinear interactions and feedback loops that are the causes and effects of one another (Cilliers 1998). As such, there are no simple solutions to problems that emerge in complex systems. The seductive idea of a 'war-time' climate mobilisation akin to the 1960s space programme ignores a key condition: technical feasibility. In contrast to stabilising the Earth's exceedingly complex biosphere, "there were no technical show stoppers in sending humans to the moon – it would just take a hell of a lot of engineering" (John M. Logsdon qtd. in Schwartz 2019). Expertise remains crucial to successful complex social interventions. However, forecasting within complex environments demands a particular kind of self-critical, adaptable, cautious, empirical, and multidisciplinary expertise (Tetlock 2017). Problem-solvers must be especially vigilant of entrained thinking, a conditioned response to a problem based on past experience, training, and success (Boone and Snowden 2007, p. 2).

Optimisation is often counter-productive. Optimisation is widely viewed as an axiomatic strategy for rational action in the world (Slote 1989). However, the defining characteristics of complex systems warns against such a prescription. Path dependence, nonlinearity and emergence all conspire to create situations of genuine uncertainty where the expectations of expected-utility theory break down. This is especially true of complex social systems which often display unexpected behaviour. Counter-intuitively, as Heiner (1983) observes, under conditions of uncertainty it may actually be our willingness to depart from the optimising standard that is the origin of stable behaviour. The inherent unknowability of complex system behaviour also implies that governance is more a matter of building resilience, than preventing surprise (Holling 1994). This means permitting 'a degree of inefficiency to ensure that the system has adaptive capacity and can therefore rapidly evolve to meet new circumstances' (Snowden 2005, p. 48). Absent highly accurate system metrics for assessing positive and negative feedback loops, optimisation on any one metric (e.g. efficiency) is likely to undermine resilience. Climate change provides a good example. Policymakers have turned expert input on the uncertainties of climate change into quantifiable fact: a dangerous 2°C limit (Shaw 2017). However, the central concern is not absolute change in one climatic measure, but multiple 'known' and 'unknown' tipping points after which predictive capacity is impaired (Lenton et al 2008). Interventions targeting complex problems require whole-system thinking.

Complex problems test the limits of human knowledge and cognition. Insights from behavioural economics, decision science and social psychology suggest that inaction on super-complex GCRs might stem partly from the 'tragedy of cognition' (Johnson and Levin 2009). As Kahneman (2011a, p. 4) notes, '[w]e are often confident even when we are wrong, and an objective observer is more likely to detect our errors than we are'. Humans tend to prioritise immediate threats and discount those that seem remote, abstract and uncertain (Zaval and Cornwell 2016). Experts are not immune from subjective bias (Tetlock 2017). Because we base risk assessments on available experience, recent events and pre-existing beliefs, we severely underestimate unfamiliar

threat scenarios such as a mass extinction event (Yudkowsky 2008). Unlike more immediate or emotionally compelling dangers, 'creeping' risks such as large-scale climate change, ecological collapse or misaligned AI are not registered as urgent moral imperatives, resulting in wishful thinking, self-defensive reactions or hostile denial of scientific findings (Markowitz and Shariff 2012). In a context of complexity, significant weight is placed on heuristics in human judgement and decision-making. Heuristics are generally defined as cognitive shortcuts or 'rules of thumb' that simplify decisions, especially under conditions of uncertainty (Kahneman 2003). However, heuristics can also lead to cognitive biases. According to Kahneman (2011b), '[t]rue intuitive expertise is learned from prolonged experience with good feedback on mistakes'.

3. Governing Complexity: New Building Codes

In sum, a key problem which GCR decision-makers confront is that they are using governance apparatuses attuned to complicated problems to govern complex problems. This legacy approach is no longer producing good outcomes. The mechanisms that are intended to ensure the system self-corrects seem to be losing purchase, unable to contend with the equifinality of growing complexity:

- Causation is almost impossible to establish

- Predictions cannot be made with precision, especially regarding the effects interventions will have on system behaviour

- Positive feedback loops, emergent properties, and novel evolving capacities all defy predictive modelling

- The risk is that, in the face of growing complexity, decision-makers will invest in ever more complicated and specialised responses to the point of catastrophic failure when exposed to severe stress.

Jervis (1997, p. 29) zeros in on the main effects of complex systems that must be taken into account if we are to understand governance:

- Effects of action are often delayed and indirect

- Relations between two actors are often determined by each one's relations with other actors—triangular relations are prevalent

- Interactions are central and non-additive

- A 'common sense' method of probing the environment cannot be trusted

- Outcomes are often unintended

- Regulation is difficult.

A growing consensus among complexity scholars is that a new systems-based scientific approach to governance is required; one that is able to accommodate the interrelationships and interdependencies of diverse elements and systems. The task is formidable, made more so by the frequent conflation of complexity with crisis. Axelrod and Cohen (2000, p. 9) argue, if we are to close the widening global governance gap, we will have to find ways of 'living with [complexity], and

even taking advantage of it, rather than trying to ignore or eliminate it'. Homer-Dixon (2007, p. 308) goes further, arguing that complex system 'breakdown, if limited, can be a key part of that system's long-term resilience and renewal'. A 'complexity sensibility' accepts that complexity is the norm, not the exception – and may even be beneficial (Lehmann 2012, p. 410). Such observations cut against established ways of 'doing governance', displaying more of an affinity with evolutionary biology than Newtonian physics (ScienceDaily 2017):

> *Randomness is the antithesis of control for humanmade systems; engineers work hard to suppress it. It is the opposite for biological systems; life thrives with and within fluctuations. At any rate, avoiding fluctuations is simply not feasible at very small scales.*

Complexity in a context of GCRs means thinking hard about complexity as a governance design problem. As the next section explores, the hunt for new building codes for governing systemic risks within large-scale social systems is underway, if not yet formally constituted. Focused less on predetermined solutions or reacting to emergent characteristics, the principled approach towards governing GCRs outlined here requires above all 'stepping into the complex system' (Klijn and Snellen 2009, p. 34); designing and enabling mechanisms and strategies capable of setting in motion and stabilising desirable complex outcomes, ever cognisant of the uncertainty posed by complex task environments.

IV. Evolutionary Design and Application: Governing Global Catastrophic Risks

"What we really need at this particular point in time is a kind of design that rather than being assembled from within a central, single, monolithic point of view, embodies a kind of diffused integration…we need design capabilities, design characteristics, that have the rapidity of top-down, but the effectiveness of bottom-up..."

Forrest Landry (in: Civilization Emerging 2017)

1. Systems Thinking and Design Science: Planned versus Evolutionary Design

Governing complex GCRs is a design problem. But what is design? How might combining complexity thinking and design science improve responses to GCRs? Can we devise a set of principles to enable novel forms of design capable of meeting the challenge of information-age threats? At root, given that governance structures are rarely designed ex nihilo, design is about devising 'courses of action aimed at changing existing institutions into preferred ones' (Simon 1996, p. 111). Design science seeks to create systematic and actionable knowledge about *how* to design such courses of action (Baskerville 2017). Outcomes may include the material artefacts that we typically associate with design, such as a building or computer information system, as well as non-material artefacts, such as public policies, management practices or global governance institutions.

The traditional *planned design* model follows a linear step-by-step process: problems are analysed by breaking them down into component parts (*problem definition*) and these observations are then synthesised, yielding a plan for implementation (*problem solution*) (Buchanan 1992). The underlying assumption is that we can arrive at optimal design solutions and define them a priori. This model of design remains pervasive in policy planning, where continuity and efficiency have long served as important measures of accomplishment (Rittel and Webber 1973). However, in a complex environment, optimal solutions are unknowable. In fact, 'there are no "solutions" in the sense of definitive and objective answers', and pathways forward may only emerge through observation, experimentation and experience (ibid, p. 155).

While the traditional model of planned design remains useful for addressing complicated engineering problems, complex problems call for a fundamentally different approach to design that selects flexibility over continuity and effectiveness over efficiency. These and other related attributes are reflected in *evolutionary design* approaches that allow for continuous incremental adaptations. The idea of evolutionary design emerged first in programming and software design, but it has increasingly found application in policy design for complex social systems, from health and education systems to urban planning (Gerrits and Teisman 2012).

Evolutionary design does not produce what software developers call a 'Big Design Up Front'.[10] Instead of attempting to define a near-perfect solution a priori, it starts with a 'good enough' model and allows for modifications to evolve and be added in an incremental fashion as patterns of change

become visible. This accepts the reality that at 'the initial stage of the design process opportunities are rife for mistakes: about what the key issue is, who the relevant parties are, cause-effect relationships, even institutional designers' true interests' (Wendt 2001, p. 1044). A 'good enough' approach does not mean, however, that design evolution is completely left to chance. While there are no pre-defined, context-independent rules for design development, system architects can use directional goals and enabling constraints – boundary conditions that do not restrict but allow for a range of possible outcomes – to steer complex systems in a desirable direction. In other words, steering a complex system towards emergent outcomes is more akin to raising a child than launching a space rocket (Glouberman and Zimmerman 2002).

An evolutionary approach privileges effectiveness in the long run over short-term efficiency. As Simon (1996, p. 124) argues, in a complex world, it is advisable 'not to follow out one line until it succeeds completely or fails definitely, but to begin to explore several tentative paths, continuing to pursue a few that look most promising at a given moment. If one of the active paths begins to look less promising, it may be replaced by another that had previously been assigned a lower priority'. Contrary to conventional wisdom, such redundancy, diversity and overlap of functions is actually desirable in complex environments, promoting experimentation and innovation. Importantly, they also enhance system resilience by ensuring that sudden failure of any individual part can be compensated by others (Biggs, Schlüter and Schoon 2015). This is vital with regard to the governance of complex GCRs. Small-scale, contained failures may encourage learning, adaptation and innovation, but system-wide cascading failures would be catastrophic. This mode of thinking is making inroads among decision-makers as the limitations of 'one-shot "big bang" policies' on super-complex problems become increasingly apparent (Levin et al 2012, p. 125).

'[D]esign is always to re-design' (Latour 2008, p. 5), and that is particularly true for evolutionary design approaches that do not work towards pre-defined end targets. This new understanding of design also challenges the sequential relationship between problem definition and problem solution. In other words, not only are responses subject to continuous refinement, but also the problem itself changes, so that problem-framing and designed solutions co-evolve (Van der Bijl-Brouwer 2019). Diagnostics are crucial but not conclusive, and problem definition is an ongoing process rather than a distinct first step. Importantly, evolutionary design approaches also acknowledge that information and knowledge in complex systems are dispersed, localised and often contested. Therefore, collaborative and deliberative processes are an inherent part of defining the problem and arriving at evolutionary design principles capable of enabling a resilient and sustainable governance response to GCRs.

2. Systemic design principles for governing global catastrophic risk

Design thinking which integrates insights from complexity theory and design science, long the preserve of systems engineering and policy planning (Nelson and Stolterman 2012), has much to offer governance research and practice. For our purposes, it invites critical reflection on how to devise design principles which can guide emergent efforts towards constituting a new toolkit for governing large-scale social systems. Jones (2014, p. 104) offers a useful definition of design principles:

Design principles offer guidelines and a foundation for practitioners to enhance engagement and evolve better practices. Principles are elicited from systems theoretic concepts, yet do not propose any new theory. They provide elements for practitioners to form new frameworks enabling integration of other concepts for specific design contexts.

A design principle approach is not intended to be prescriptive, but rather to meet the demands of creative complexity, namely, to combine a stable evolving framework which can allow for as wide a variety of local interactions as possible. Design is that which agents do deliberately. Using principles, they try to anticipate the needs of governance recipients and future ideal states, with a view to enabling 'appropriate, organized high-leverage action in the increasingly complex and systemic problems as *design situations*' (ibid, p. 105). In another sense, this is an exercise in clarifying complexity. Table 2 presents a general design model for governing GCRs, with principles categorised according to major phases in the process of addressing complex problems. In practice, these phases are not mutually exclusive and there is likely to be significant overlap (for example, transparency will be vital to trust across phases). In turn, the more complex the problem, the more likely rapid repeat iterations across all three meta-phases will be necessary.

Table 2. Systemic Design Principles for Governing Complex Global Catastrophic Risk

Problem type	Complex, where openness, emergence and non-linearity produce frequent surprises
Goal	Resilient and sustainable design that survives by constantly evolving and adapting to changing circumstances
Governance Phases	**Systemic Design Principles**
Exploration and discovery	1. Assessing scope of complexity 2. Enhancing sensitivity to complexity 3. Transparency 4. Deliberation and participation
Designing and enabling	1. Ordering complexity 2. Boundary-setting and enabling constraints 3. Experimentation and learning 4. Self-preservation (fail-safe)
Stabilisation and evaluation	1. Leverage points 2. Feedback coordination and course correction 3. Evaluation and ratcheting 4. Conflict resolution and collective discipline

3. Design principles and prototypes: governing complex global catastrophic risk

This section provides a snapshot of key scholarship and real-world innovation which is putting these design principles into practice. This exercise is necessarily speculative, drawing upon nascent post-industrial governance prototyping. Application to GCRs is similarly experimental. In the field of pathogen oversight, for example, experts readily admit that 'there is very little precedent to work with' (Steinbruner et al 2007, p. 2). Complex governance is being deployed, often uneasily, within existing legacy structures. This may hold out the hope for 'refactoring' (undertaking a sequence of small system-preserving changes) to cumulatively produce significant transformation (Fowler n.d.). However, others are more sceptical. The cognitive limits of humans will often thwart efforts to intend successful refactoring. In turn, 'the exercise of foresight', as Holling (2001 p. 401) wryly observes, 'is often brilliantly directed to protect the positions of individuals rather than to further larger societal goals'.

Ultimately, this overview exercise raises as many questions as answers: How do you design GCR prevention mechanisms that produce the benefits of hierarchy at scale without the costs? Can new governance systems leverage legacy structures to gain capabilities rapidly and supplement deficits? What is the minimum viable scale to start prototyping new forms of GCR governance? Can you prevent harm ('negative externality') that is incentivised by the geopolitical and macroeconomic system? Responding to such problems will require extraordinary depth of understanding.

3.1.   Problem Identification: Exploration and Discovery

In a complex world, decision-makers cannot ever fully define, understand and predict the problems they face. Nevertheless, the risk of catastrophic systemic failure demands that we continuously seek to 'make sense' of complex problems in their changing contexts (Kurtz and Snowden 2003).

i.   *Assessing scope of complexity.* Sense-making enables comprehension of ongoing complexity which can serve as a springboard into action (Weick 1995). A situational whole-systems understanding of the problem is required. Sense-making has an explicitly forward-looking orientation, but its goal is not to offer predictions but to identify and connect 'chains of contingencies that could shape the future' (Bernstein et al 2000, p. 53). How long do we have before ocean acidification destroys all of the coral? What are the real risks posed by parasitic AGI? It is crucial that planners can make sense of such developments, otherwise it is not possible to prioritise. For some observers, a loss of sense-making is itself a serious existential risk (Schmachtenberger 2017).

Innovation: Tools such as the Cynefin framework (Snowden and Boone 2007) or the Stacey matrix (Stacey 2002) can help decision-makers assess the situations they operate in, supported by new modelling and data analysis methods. Policy-makers can also make use of new visualisation tools, such as 'fitness landscapes' which may reveal informative patterns of complex system behaviour over time (Geyer and Pickering 2011).

ii.   *Enhancing sensitivity to complexity.* Complex problems cannot be modelled without comprehensive data. As Holling (2004) notes, the 'key feature of a sustainable adaptive

system is the need to recognise the sustaining properties of slow variables'. This poses a key challenge to expert judgement. While fast, dynamic variables trigger readily-observable change, it is crucial that GCR analysts also pay attention to the slower variables where change is harder to detect. Big and open data initiatives hold much promise for identifying such indicative patterns in large-scale complex social systems (Gurin et al 2015). However, to be useful, they require an 'openness of analysts and policy makers to discontinuities, a curiosity about anomalous data, and a willingness to engage in speculative thinking' (Feder 2002, p. 114).

Innovation: Examples of initiatives on the global level include the Open Data for Resilience initiative (OpenDRI), which seeks to '[apply] open data practices to help reduce vulnerability to natural hazards worldwide' (OpenDri n.d.), and the FuturICT project, which explicitly aims to use the power of big data to make sense of planetary-scale complex problems (FutureICT n.d.). However, the move towards big and open data also introduces new layers of complexity itself, raising concerns regarding its management, quality and credibility, along with the fear that it 'may widen existing inequalities and social divides' (Leonelli 2018).

iii. ***Transparency.*** GCR governance should be transparent by design (not just by intention). This is necessary to neutralise game theoretic dysfunctions which create incentives for powerful actors to hoard information. For example, in 2006 Indonesia refused to share samples of the H5N1 avian flu virus, collected from Indonesian patients, with the WHO, claiming national security concerns (Hameiri 2014). The Paris Agreement's reliance on state-led voluntary pledges must contend with 'misleading promises and politically motivated information' (Keohane and Victor 2016, p. 572). Scholarship suggests at least two key mechanisms for enhancing transparency: first, appropriately designed information environments (Kelley 2017); second, respondents (or 'targets') who trust regulators are more likely to generate accurate information (Edelenbos and Eshuis 2009, p. 208).

Innovation. Big and open data initiatives may also increase accountability and transparency of governance interventions, encourage collaboration and promote public participation in decision-making (Gurin et al 2015). This can be observed in the phenomena of 'citizen science' (Irwin 1995). New technology such as blockchain could also enhance transparency and trust through decentralised peer-to-peer verification. Frontier applications, such as *Mattereum*, are being deployed to tackle environmental and social harms (Gupta 2019).

iv. ***Deliberation and participation.*** Deliberative mechanisms should complement expert assessments by ensuring a 'flow of experiential knowledge through the system so that they enable the actors in the system to produce, appreciate, and select productive intervention strategies' (Wagenaar 2007, p. 18). The critical importance of knowledge co-production with local and indigenous communities is well-established. In conservation research, it 'has contributed to assessing and monitoring forests, wildlife, marine ecosystems or cultivated biodiversity, and provides critical knowledge about biodiverse but understudied regions' (Reyes-García and Benyei 2019, p. 657). Such mechanisms can enhance anticipation of distributional or value conflict (Newey 2019).

Equally important, such mechanisms can raise public awareness of complex global problems, build public support for policy change, and mobilise communities to take action themselves (Hovmand 2014).

Innovation. There are several ways in which citizens can be directly engaged in problem diagnosis, from popular assemblies to mini publics to e-democracy (Smith 2009). Currently, such deliberative fora exist primarily on the national and local level. Developments in e-democracy may provide new opportunities for transnational public deliberation and decision-making, although tools to support this – such as *Democracy Earth* (Democracy Earth n.d.) or *DemocracyOS* (DemocracyOS n.d.) – are still in their infancy. Within the current blockchain ecosystem, the most significant attempt to create decentralised participative governance models is the DAO ('decentralised autonomous organisation') (Hsieh et al. 2018).

3.2.   Designing and Enabling Policy Responses

Complex problems such as GCRs are not static; any intervention changes the situation in unforeseeable ways, and non-linearity produces frequent surprises. Broad goal-setting requires supplementing with strategic exploration of possibilities by many agents. Designing and enabling responses to GCRs will require continuous learning, through coordinated experimentation, simultaneous probing of strategies, feedback loops on success and failure, rapid action to correct failure before they cascade, and incentives for scaling up success.

i.   ***Ordering complexity.*** Polycentric governance theory pioneered by Elinor Ostrom (2010) has demonstrated that effective responses to 'wicked problems' often emerge from bottom-up dynamics, absent central command-and-control. Modes of collaboration that underpin these responses are diverse, transcending the traditional dichotomy between state and market (ibid). Complex governance is not an exercise of superimposition by a 'trans-historical designer' (Wendt 2001, p. 1037), but rather the enabling of progressive, if imperfect, adaptation towards orderly complexity (Jessop 1998, p. 33). This process has been termed 'meta-governance' (Sørensen and Torfing 2009) or 'experimentalist governance', understood as 'an institutionalized process of participatory and multilevel collective problem solving, in which the problems (and the means of addressing them) are framed in an open-ended way, and subjected to periodic revision by various forms of peer review in the light of locally generated knowledge' (De Búrca, Keohane and Sabel 2014, p. 477).

Innovation. The Paris Agreement on climate change and the Sustainable Development Goals (SDGs) are both ambitious attempts to steer super-complex global policy problems towards orderly complexity. A complex governance approach is well captured by Hale's framing of the Paris Agreement as embracing a 'catalytic' model of cooperation, breaking with the legacy 'regulatory' approach (Hale 2017). Many SDG stakeholders advocate for enhancing 'UN metagovernance' of sustainability through systems-wide principles, rules and procedures (Beisheim and Simon 2018).

ii.   ***Boundary-setting and enabling constraints.*** To nudge complex systems towards sustainability, designers often set broad boundaries that cannot be crossed (e.g. Steffen

et al 2015). Within these boundaries, however, decision-makers should allow for a wide variety of bottom-up innovation and learning, recognising that '[c]omplexity is all about making changes in the present with a sense of direction but not with a specific goal, other than in very limited circumstances' (Snowden 2016a). The setting of broad boundaries is also synonymous with 'enabling constraints'. Enabling constraints do not prescribe behaviour, but enable or catalyse interaction and collaboration with a broad shared purpose, thus guaranteeing some coherence through minimal restriction. Norms or heuristics, for example, are enabling constraints that provide general orientation but 'can adapt to the unknowable unknowns' that will almost inevitably arise in a complex system (Snowden 2015).

Innovation. Perhaps the most consequential post-industrial application of enabling constraints is the creation of Representational State Transfer or 'REST' architectural constraints by Roy Fielding 2000. REST established a uniform protocol for the internet which took the form of key constraints that the web needed if it was to continue to scale without reaching a critical point of system breakdown. REST provides high level design guidelines, it does not prescribe rules, and it leaves lower level implementation to individual decision-makers (Fielding 2000).

iii.   ***Experimentalism and learning.*** Small-scale experiments are key to 'probing' the behaviour of a complex system (Snowden and Boone 2007). Experimentation should correspond to (at least) three scope conditions: that it will not break the system, that it promotes cumulative learning, and that it allows the system response to adapt to changes. Experimentation may emerge spontaneously, but it can also be orchestrated using enabling constraints. Importantly, these experiments should not be viewed as a recipe for finding the 'right' solution but as a way to explore how the system behaves and a basis for directing resources towards productive strategies. Policy-makers should also be aware of the challenges associated with scaling up successful local pilot experiments to a higher level or across contexts (West 2017).

Innovation. Environmental governance under the Paris Agreement is a test ground for diverse, parallel and continuous experimentation. The development of enabling constraints to encourage non-state actor action has been a notable new development following the 2015 Paris Agreement, which has positioned the United Nations Framework Convention on Climate Change (UNFCCC) as a central node of an explicitly 'catalytic and facilitative' regime (Hale 2016). However, the success of such initiatives will hinge largely on the ability of non-state actors to participate within local political processes. The risk is that dominant local interests will use their power to impose their preferences upon local experimentation initiatives.

iv.   ***Self-preservation (fail-safe).*** Given that small differences and the introduction of new elements can significantly alter outcomes in complex systems, governance requires adopting multiple safe-to-fail experiments. As Law (2000, p. 14) notes, in complex systems 'perfection is not only impossible but, more strongly, it may be self-defeating'. As such, policy-makers are advised to cultivate a self-reflexive 'irony' where they 'must recognise the likelihood of failure but proceed as if success were possible' (Jessop 2003 p. 110). Because learning inevitably involves failure, they must also learn how to 'fail

safely'. Indeed, if contained, failure can increase a complex system's long-term sustainability (Homer-Dixon 2007). However, GCR planners must ensure that individual experiments have a low cost of failure and do not pose a systemic risk through processes of contagion.

Innovation. Vigorous debate surrounds 'gain-of-function' (GOF) experiments involving pathogens with pandemic potential, such as the influenza virus. Such experiments may enhance understanding of disease-causing agents, but also often increase transmissibility and/or virulence of pathogens, posing a biosecurity hazard (Selgelid 2016). The National Advisory Board for Biosecurity oversees GOF experiments in the US. Geoengineering in the climate domain provokes similar concerns. While some scientists argue for 'properly designed field-experiments of limited duration and scale' (Blackstock et al. 2009, p. 38), others caution 'that real-world experimentation actually becomes deployment' with unpredictable consequences (ETC Group 2009). The US and Saudi Arabia are reportedly blocking global regulation of geoengineering (Watts 2019).

3.3. Stabilisation and Evaluation of Policy Interventions

In an evolutionary design context, the designer is never finished. A number of design principles focus upon stabilising system dynamics through strategic intervention, responding to unintended consequences, stabilising reciprocal expectations among participants, and rebalancing power differentials in the interests of system integrity and social cohesion.

i. *Leverage points.* Leverage points are 'places within a complex system where a small shift in one thing can produce big changes in everything' (Meadows 1999, p. 1). Leverage points use positive feedback to drive the system in a desirable direction and negative feedback to stabilise the system. Identifying these points is often an exercise in counter-intuition. Donnella Meadows identifies twelve places to intervene in a complex system, arguing that the most powerful – but also the most contentious – are those that shift or transcend the mindset or paradigm of a complex system (i.e. the shared ideas that underpin its goals, structures, rules and other parameters). Negative feedback may take the form of enabling constraints, where participants agree to exercise self-restraint as appropriate to avoid adverse repercussions on other actors or systems.

Innovation. Regulating nuclear proliferation consists largely of controlling plutonium and enriched uranium. This 'complicated' logic breaks down when the raw materials for information-age threats are everywhere. Experts acknowledge that a blanket moratorium on genome-editing is impractical, suggesting instead targeting the funders of scientists (Reardon 2019). Provocatively, Meadows suggests that slowing economic growth may be the key leverage point available to solve many of the world's most wicked problems: 'The world's leaders are correctly fixated on economic growth as the answer to virtually all problems, but they're pushing with all their might in the wrong direction' (Meadows 1999, p. 1).

ii.   ***Feedback coordination and course correction.*** A systems approach to governing complex problems privileges assessment of feedback effects and responsiveness to corrective information (Richardson 1991). Information which allows participants to monitor feedback over time facilitates the co-design of adaptive responses, especially when interventions provoke unintended consequences. As such, the stability of a feedback system, and the conditions producing instability, are of central concern. This may be particularly consequential to pursuing feedback loop closure (internalising 'negative externalities' in cost equations) (Banis 2019), as well as attributing responsibility to actors externalising harm to the commons. Feedback also permits system participants to be responsive to positive unintended consequences or 'exaptation' (Parry 2013), noticing unexpected side-effects, then repurposing. Such feedback coordination is important to system resilience and strategic flexibility.

Innovation. Feedback coordination requires sufficiently accurate metrics coupled with sufficient resources to generate real-time information. Integrated Pest Management (IPM) serves as an influential example of whole-system approaches to complex problems. It works by targeting metrics and a life-cycle model of pest species, enabling many small strategic interventions (Barzman et al 2015). IPM has been adopted to pursue SDG goal 15: 'protect, restore and promote sustainable use of terrestrial ecosystems (DSDG n.d.). Global supply chain management is another domain where non-state actors, such as the Global Reporting Initiative, are advancing the frontiers of feedback coordination based on public and accurate data (GRI n.d.).

iii.   ***Evaluation and ratcheting.*** In complex systems, "you define the present and see what you can change. You define a direction of travel, not a goal" (Snowden 2016b). In contrast to a complicated system, actions in complex systems 'change the environment in which they operate' and as such 'identical but later behaviour does not produce identical results' (Jervis 1997, p. 55). These observations highlight a key point: problem and response co-evolve. As such, systemic responses to complex problems requires continuous evaluation (searching, judging, measuring, verifying) to assess policy blockage, drift, and productive strategy adoption. However, evaluation should not be equated with conventional problem-solving, given that 'wicked problems' do not lend themselves to a predefined set of potential solutions or corresponding metrics (Rittel and Webber 1973). Evaluation of complex problems will therefore often rely on vector measures to assess the direction and speed of travel, as well as scope for 'ratcheting up' ambition.

Innovation. The Global Preparedness Monitoring Board, established by the World Bank and World Health Organization in the aftermath of the 2014-2016 Ebola epidemic, has a mandate to assess global preparedness to protect itself in the event of health emergencies (GPMB 2019). The Sendai Framework for Disaster Risk Reduction offers an unusually comprehensive and integrated evaluative framework (UNDRR n.d.). The success of the Montreal Protocol is attributed by some observers to its ability to 'ratchet down existing commitments at a rate that countries would tolerate' through a regulatory system 'closely connected to technical assessment and extensive review' (Sabel and

Victor 2016, p. 9). Emulating this logic, the Paris Agreement also contains a 'ratchet mechanism' to enhance ambition over time (Yeo 2016).

iv. ***Conflict resolution and collective discipline.*** Systemic design for complex GCR governance must also be resilient to capture, internal corruption and rogue activity. This is a vexing design problem. There is no hierarchy at the global scale capable of delivering costs to individuals who are moved to violate the collective interest. This is a serious concern as exponential technology requiring no special-purpose facilities accelerates the asymmetric power of (potentially psychopathic) individuals. Even where local hierarchy is effective, it is corruptible, often predatory and prone to polarisation. Indeed, Martin Rees identifies low trust in authority and unprecedented global inequality as under-appreciated threats (see Conn 2018). Frontier research is probing novel democratic mechanisms to resolve distributive conflict at scale (Bauwens, Kostakis and Pazaitis 2019). Other scholars are investigating collective discipline through decentralised reputational architectures, enmeshed in trust mechanisms (Watt and Wu 2018). Ultimately, complex governance requires responsible agents, guided by an ethical orientation which acknowledges that there is no 'outside'; no 'view from nowhere' (Cilliers 1998).

Innovation. Proposals for conventional regulation of GCRs through moratoriums, monitoring and precautionary mechanisms are prevalent (Sunstein 2007). Voluntary peer review mechanisms, such as the Universal Periodic Review within the UN human rights system offers the promise of enforcing collective discipline through strategic relationships (Terman and Voeten 2018). When it comes to emergent GCRs, such as nanotechnology (Foss Hansen et al. 2013), synthetic biology (Gronvall 2015), quantum computing (Majot and Yampolskiy 2015), and autonomous AI weaponry (OHCHR 2013), experts on the ground voice concern over time wasted, the short-term limitations of current regulation, the absence of preventive and mitigating action, and the absence of effective containment. EU plans to control the use of facial recognition data will be watched closely (Khan 2019).

V.   Conclusion

'We are all in a situation that resembles driving a fast vehicle at night over unknown terrain that is rough, full of gullies, with precipices not far off. Some kind of headlight, even a feeble and flickering one, may help to avoid some of the worst disasters.'

Murray Gell-Mann (1994, p. 366)

This knowledge overview paper has explored the implications of complexity thinking for governing global catastrophic risks (GCRs), in particular, a new breed of super-complex GCRs. It has explored why many complexity experts regard it as crucial to distinguish between 'complicated' and 'complex' problems. It has used this framing to offer a novel interrogation of why legacy governance structures are 'not fit for purpose' when it comes to responding to the complex drivers of GCRs. This assessment has provided the basis for an exploration of systemic design principles which could serve to guide policymakers and other participants seeking to innovate upon existing governance configurations in the face of mounting global complexity and risk imperatives. This exercise suggests that establishing the right relationship between overlapping complicated and complex domains is a necessary condition for any design criteria underpinning governance of a viable global civilisation.

The stakes could not be higher. Many experts believe that global catastrophes are possible, even probable in the long run. A complex governance approach to governing these risks holds out the promise of preventing calamitous failure. Contrary to conventional belief, 'constrained breakdown' may be desirable; setting in motion processes of restructuring, renewal and long-term adaptation, as found in natural ecological systems (Gunderson and Holling 2012). However, threading the needle of constrained breakdown as opposed to chaotic collapse poses a daunting challenge: what does it mean to govern in an ever-changing, interacting, nonlinear, kaleidoscopic world?

To govern at 'the edge of order and chaos', Waldrop (1993, p. 333) suggests, is 'to keep as many options open as possible. You go for viability, something that's workable, rather than what's 'optimal'…you're trying to maximise robustness, or survivability, in the face of an ill-defined future'. Building upon such observations, this paper has integrated complexity theory and governance scholarship and design science to arrive at a set of governance principles designed to respond to the complex drivers of GCRs, holding out the promise of imprinting a new logic of change onto global governance structures beyond top-down regulation. In so doing, it makes progress in devising a research and practical policy agenda which moves debate beyond the notion of *determining* complicated outcomes, to *enabling* complex outcomes (Adams et al 2014).

Appendix A: Complex International Relations: An Unfulfilled Promise

Complexity theory (and in particular Complex Adaptive Systems) has long-informed International Relations (IR) research (Rosenau 2003; Jervis 1997). Compared to other fields though, such as human geography, economics, evolutionary theory and computing, mainstream IR has been slow to embrace complexity theory. This is not for want of trying by advocates of 'Complex IR' (Bernstein et al. 2000; Bell 2006; Kavalski 2007; 2015). However, IR has long sought to establish itself as a positivist scientific enterprise, able to produce relatively enduring, universally applicable insights (Hoffmann and Riley 2002). Dominant IR theories, such as structural realism and neoliberalism, are often assumed to be exemplars of systems theory, privileging a statist, analytic, reductionist, linear and rationalist approach to the study of global politics. However, as Donnelly (2019, p. 904 and 910) convincingly argues, they are in fact 'the antithesis', omitting a 'systemic frame of emergent levels of organization, aggregation, or complexity'. Despite their systemic starting points, Donnelly shows that what was produced is actually an analytic theory focused on states as autonomous units interacting under fixed structural conditions of anarchy, not as parts of a system.

As such, a complexity theory perspective sits uneasily with much IR scholarship, particularly in the US, where rational choice modelling and statistical analysis dominate the study of global affairs, to the exclusion of systems thinking (Monteiro 2012, p. 347). Complexity theory's focus on constant, non-linear change may offer a more accurate account of the dynamism, unpredictability and pace of change in global politics. But taking non-linearity seriously also invites acknowledging the reality that the knowledge IR scholars are able to generate will inevitably have a limited shelf life, degraded by the 'information-entropy cycle' (Oatley 2019: 972). However, the cause of complex IR has not been helped by ambiguity surrounding complexity theory itself, what Waldrop (1993) referred to as 'the emerging science at the edge of order and chaos'. Rosenau (1999, p. 53) who boldly attributes to complexity theory 'the potential for clarifying and ultimately ameliorating the human condition', would have to admit that this potential is still far from being realized.

Hurrell (2007: 293-4) may be right that '[g]overnance will need to confront the poorly understood complexity of natural systems, the increasing complexity of human and social systems, and increasing rates of technological change', but observers wonder whether 'complexity theory can fill the gap' (Levy 2000: 74). Many IR scholars would appear to agree with Kissane (2007: 100) that 'the theorist has to make a choice as to which actor or level of interdependence they will restrict their analysis to'. This pragmatic position is well-represented in the scholarship and has made significant contributions to clarifying the problems raised by the behaviour of complex systems. It has also contributed to understanding the challenges of governing a globalized world politics, composed of a multiplicity of market and civil society actors, played out through diverse informal, yet norm-governed, processes, and complex networks, operating at multiple scales of aggregation (Cutler et al. 1999; De Búrca et al. 2014; Kahler 2009; Farrell and Newman 2016; Krasner 2011; Abbott et al. 2017). Complexity theory, especially in the form of complex systems dynamics, continues to filter into global governance scholarship and shows no signs of abating. Donnelly (2019: 16) boldly suggests 'that relationalism is 'poised to make the major, even revolutionary, "systemic" contributions that…structural realism failed to deliver'. Time will tell as to whether this latest prediction will come to pass.

Endnotes

[1] Albert Einstein qtd. in Calaprice (2000).

[2] Donald Rumsfeld qtd. in Shermer (2005).

[3] For early exemplars, see: Holling (1973), Pressman and Wildavsky (1996), Walker and Salt (2006).

[4] 'The likelihood that a human-driven global catastrophe will occur in the next 20 years is uncertain, and probably low' (CSER 2019, p. 2).

[5] The troubling implications of new technology, such as encrypted 'darknets' drones, and personal fabrication such as 'Deepfake' are self-evident (see Aljazeera 2019).

[6] A 'complexity sensibility' reflects Urry's notion of a new 'structure of feeling' produced by the complexity turn, which 'involves a sense of contingent openness and multiple futures, of the unpredictability of outcomes in time-space…' John Urry (2005), 'The Complexity Turn', *Theory, Culture & Society* 22, p. 3.

[7] Khalil argues that the appropriate distinction is between 'the real' and the 'artificial'. E. L. Khalil, 'Social Theory and Naturalism', in: E. L. Khalil and K. Boulding (eds.), Evolution, Complexity and Order (London: Routledge, 1996), pp. 1–39.

[8] Less poetic than Waldrop, Bernstein et al. (2000, p. 48) oppose the 'bounded invariance' found in closed systems with open systems which 'can be influenced by external stimuli, and their structure and their causal mechanisms evolve as a result' (p. 48).

[9] Scale-free networks is one that obeys a power law distribution in the number of connections between nodes on the network. Some few nodes exhibit extremely high connectivity (essentially scale-free) while the vast majority are relatively poorly connected. See: Barabási and Bonabeau (2003).

[10] Examples of 'Big Design Up Front' from global governance may include disease elimination campaigns (Henderson and Klepac 2013).

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